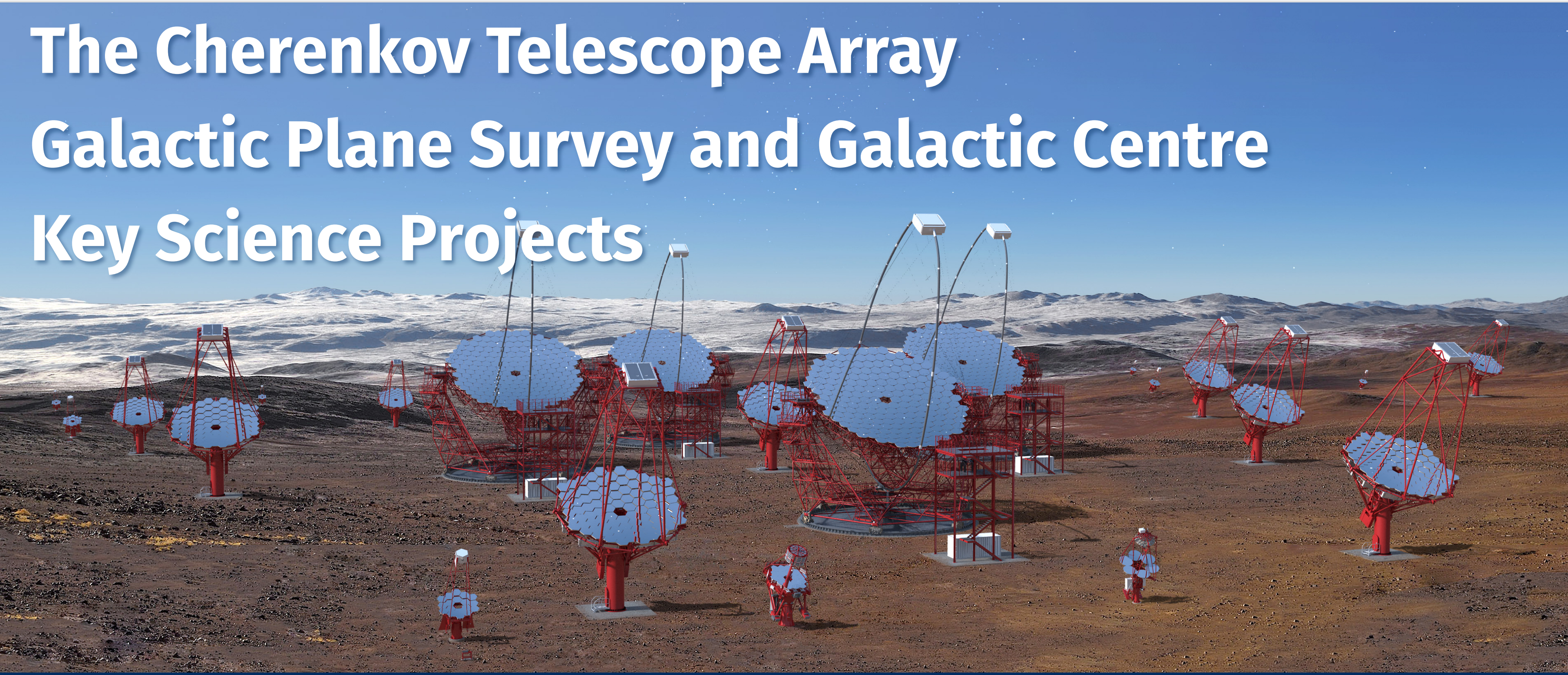
The Cherenkov Telescope Array Galactic Plane Survey and Galactic Centre Key Science Projects



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Outline

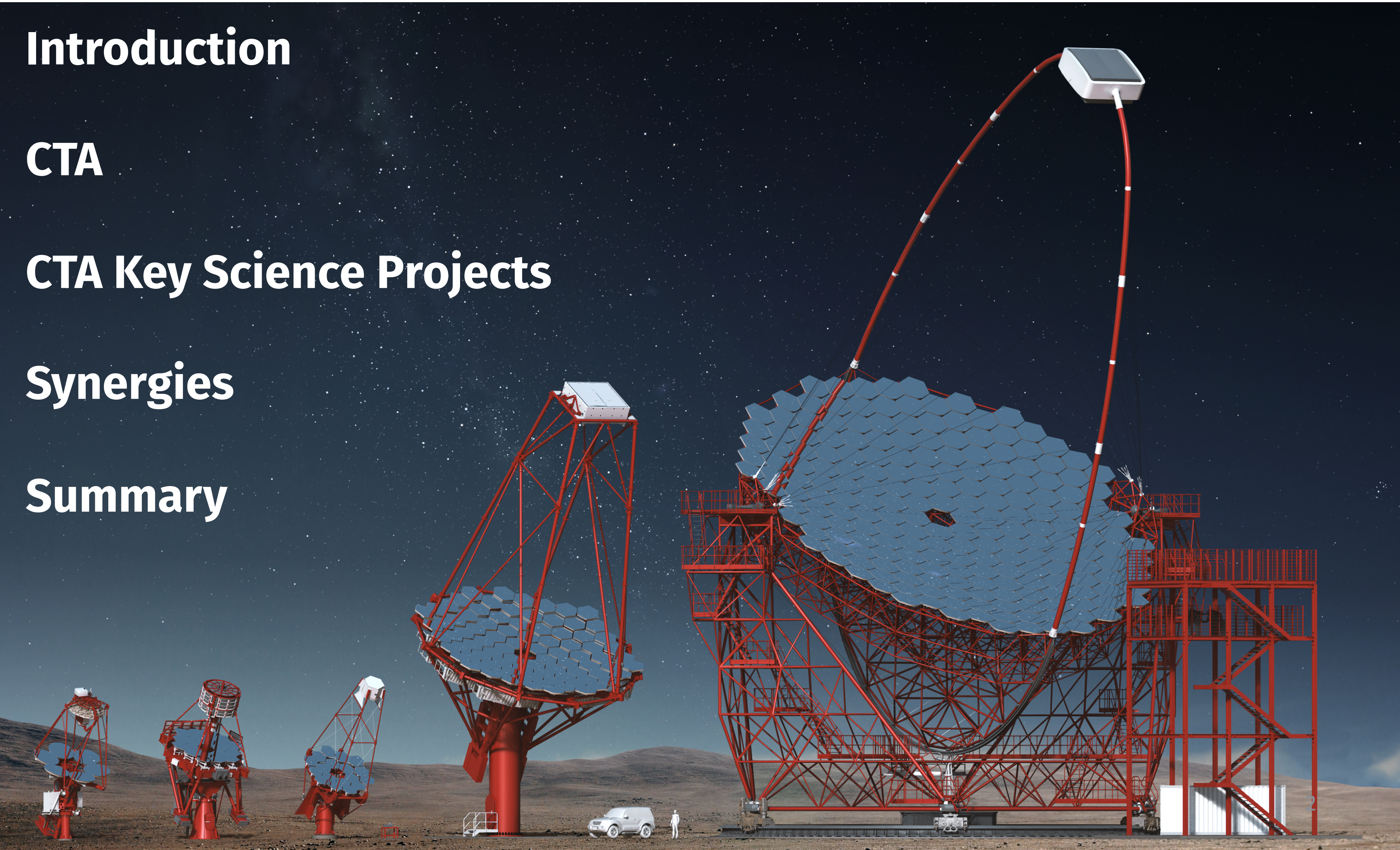
Introduction

CTA

CTA Key Science Projects

Synergies

Summary



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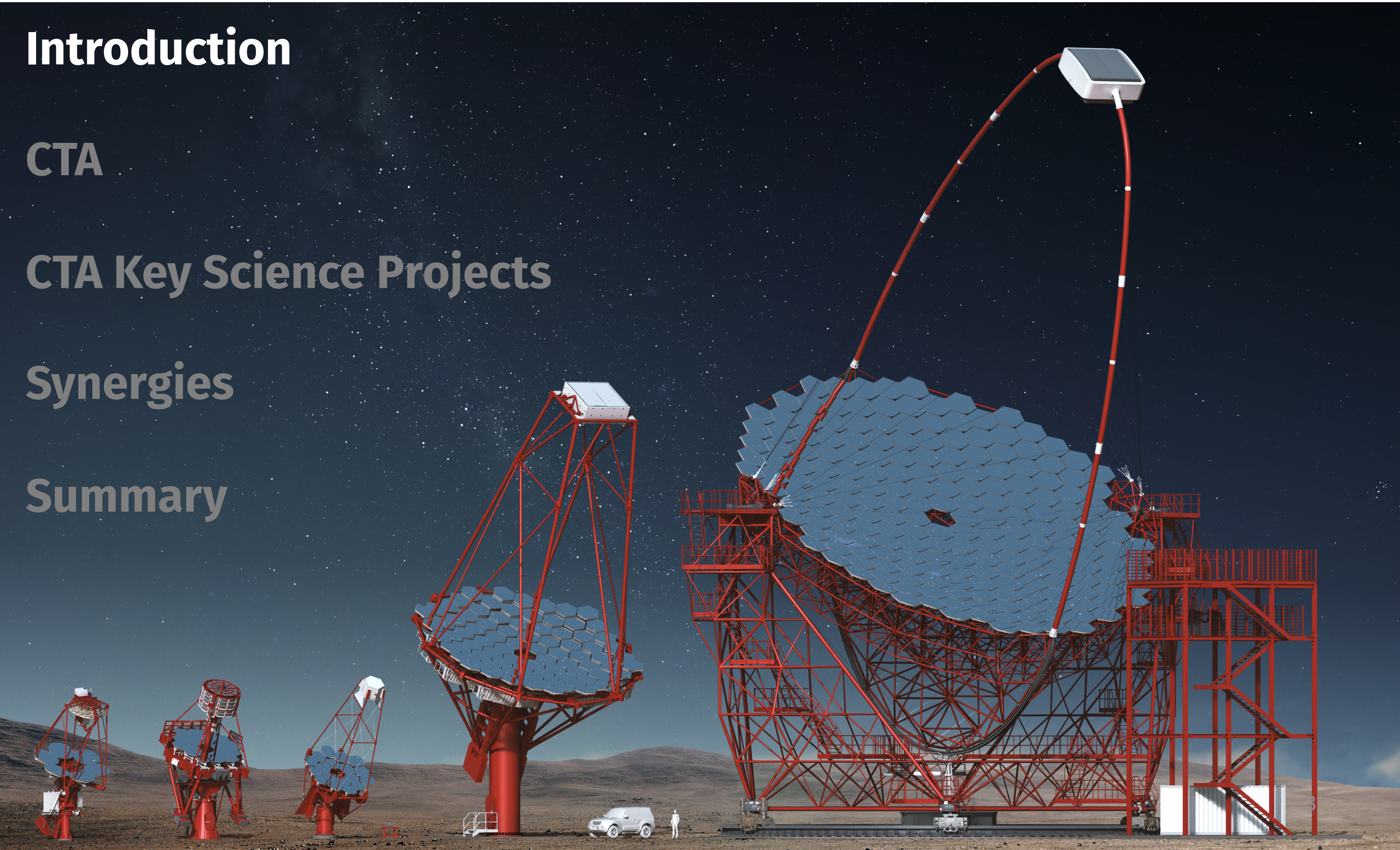

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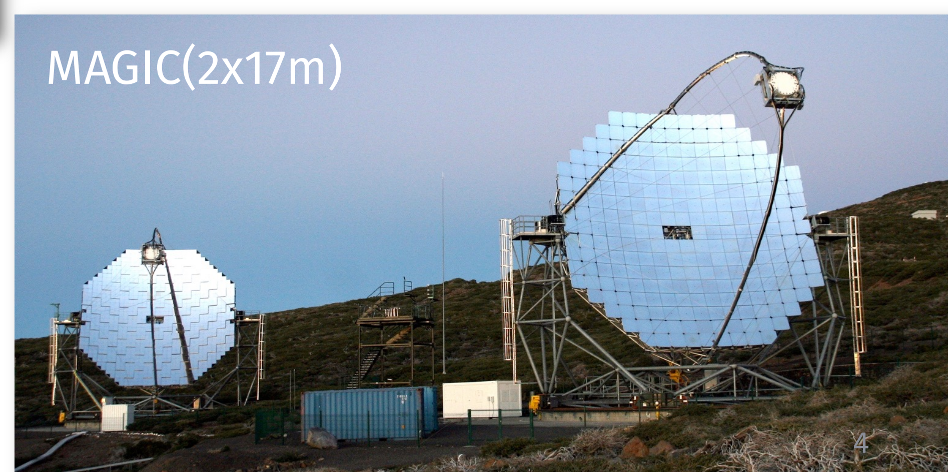
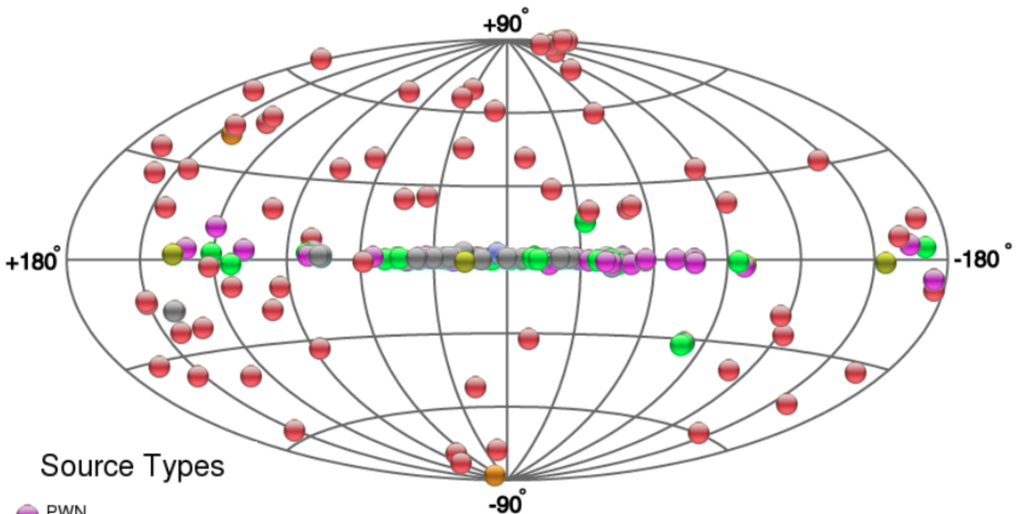
The current IACT status

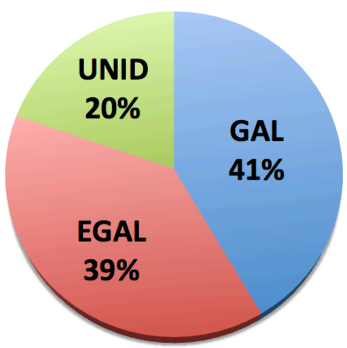


The sky above 50 GeV



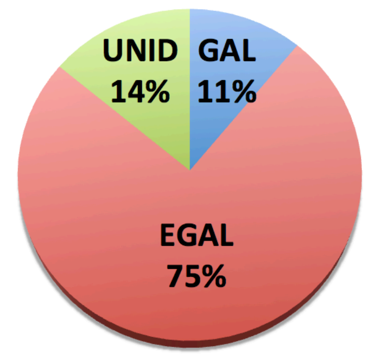
Wakely & Horan http://tevcat2.uchicago.edu/

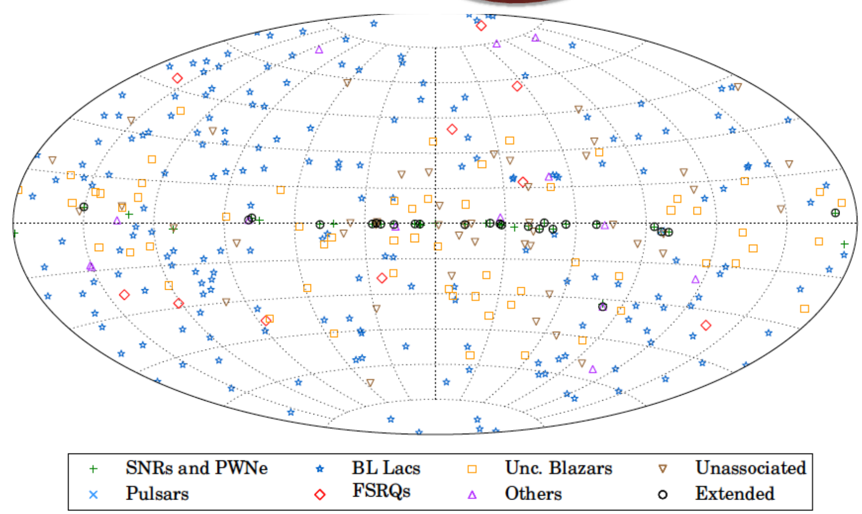
~200 TeVCat sources



H.E.S.S.
MAGIC
VERITAS

360 *Fermi*-LAT sources E>50 GeV

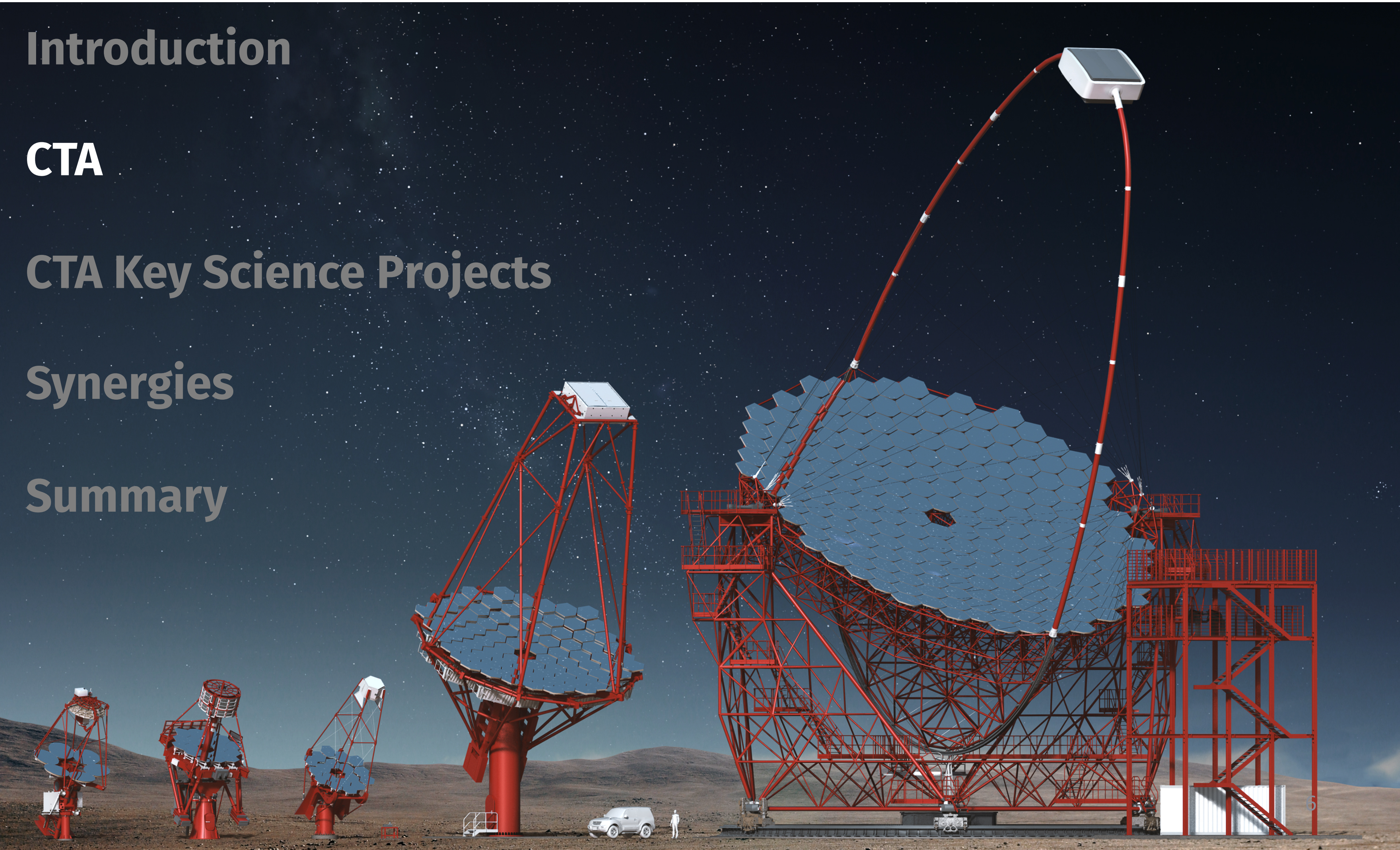




2FHL Ackermann+16

Only ~25% of the 2FHL sources have been previously detected by Cherenkov telescopes.
2FHL provides a reservoir of candidates to be followed up at very high energies.

Outline



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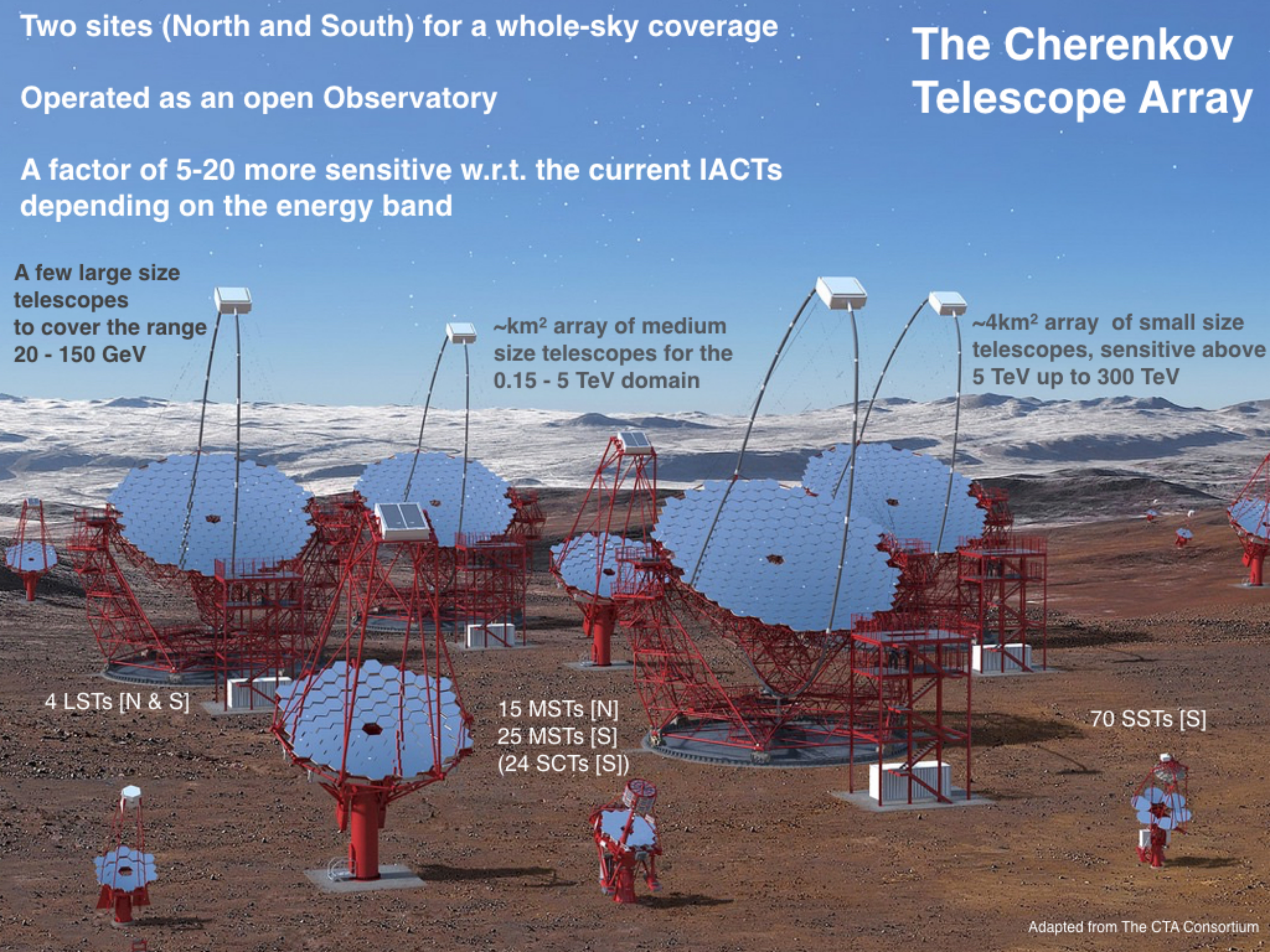


Two sites (North and South) for a whole-sky coverage
The Cherenkov Telescope Array
Operated as an open Observatory
A factor of 5-20 more sensitive w.r.t. the current IACTs depending on the energy band
A few large size telescopes to cover the range 20 - 150 GeV
~km² array of medium size telescopes for the 0.15 - 5 TeV domain
~4km² array of small size telescopes, sensitive above 5 TeV up to 300 TeV
4 LSTs [N & S]
15 MSTs [N]
25 MSTs [S]
(24 SCTs [S])
70 SSTs [S]
Adapted from The CTA Consortium

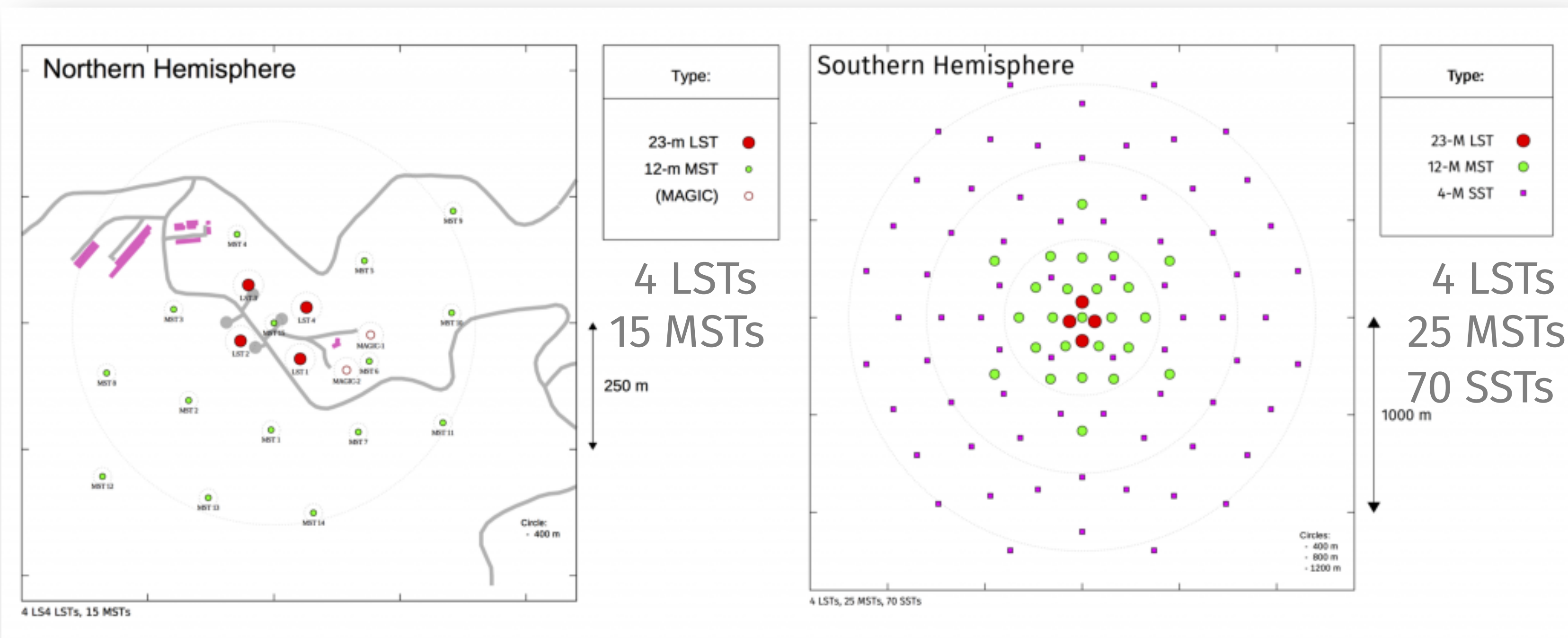
Where to find us

High-level timeline and proposed layout

Project Phases

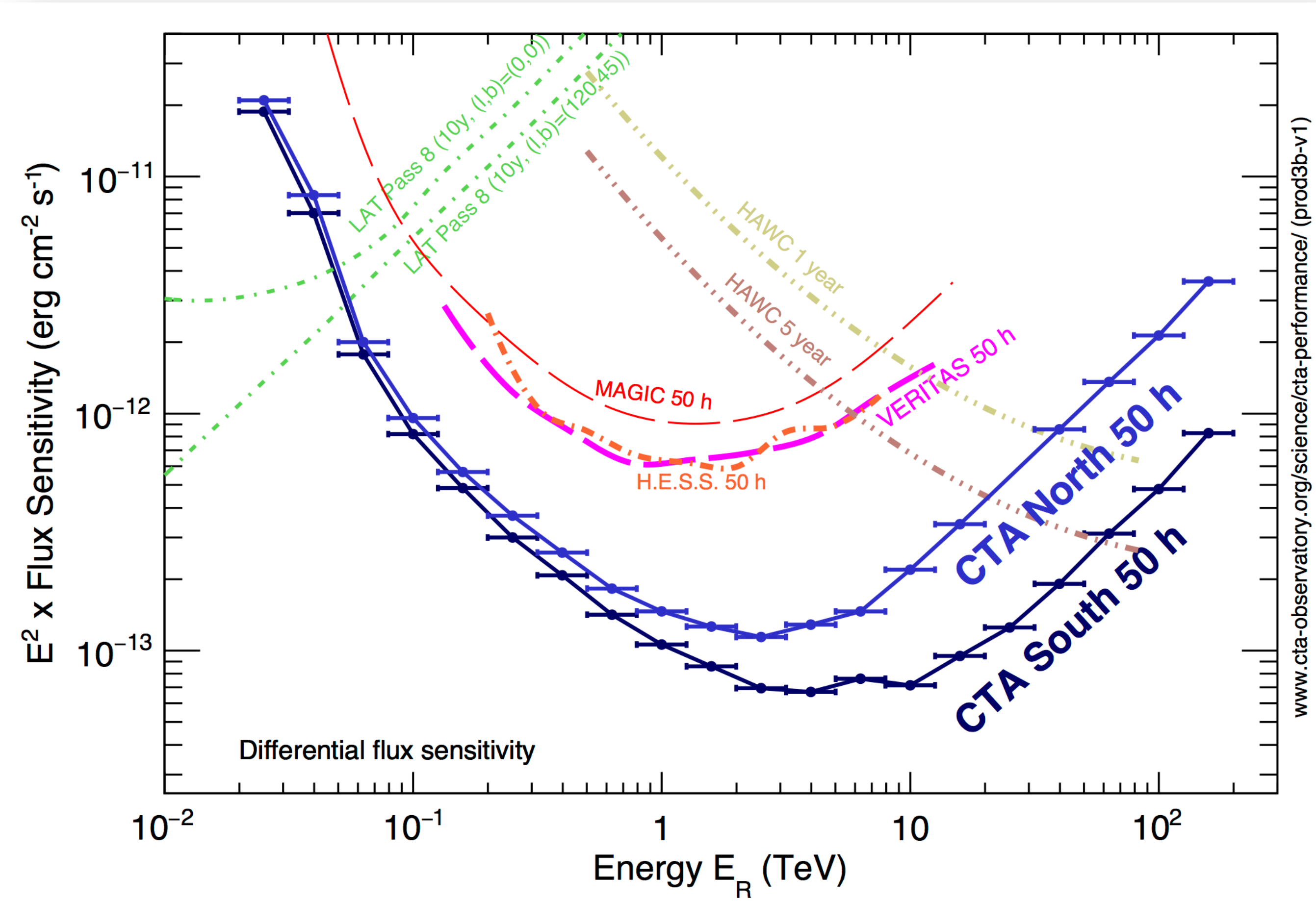
Pre-Construction	Pre-Production	Production
Current Phase	2019-2021	2021-2025

First Pre-Production Telescopes on Site



CTA Performance

Differential Sensitivity

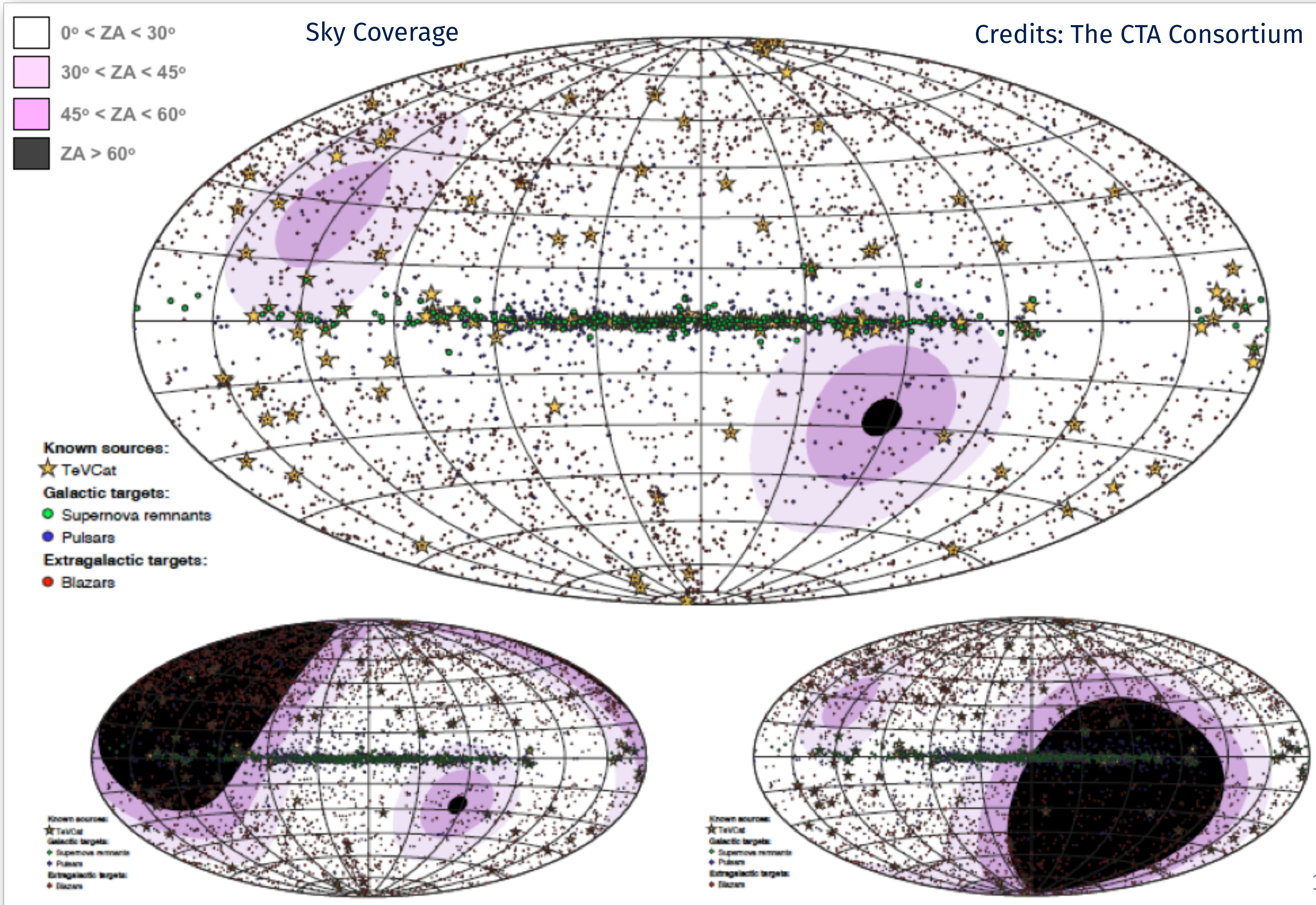


A factor of **5-20 improvement** in sensitivity depending on energy, relative to current IACTs.

Extension of the accessible energy range from **well below 100 GeV to above 100 TeV**.

https://www.cta-observatory.org/science/cta-performance/

CTA as an *all-sky* Observatory



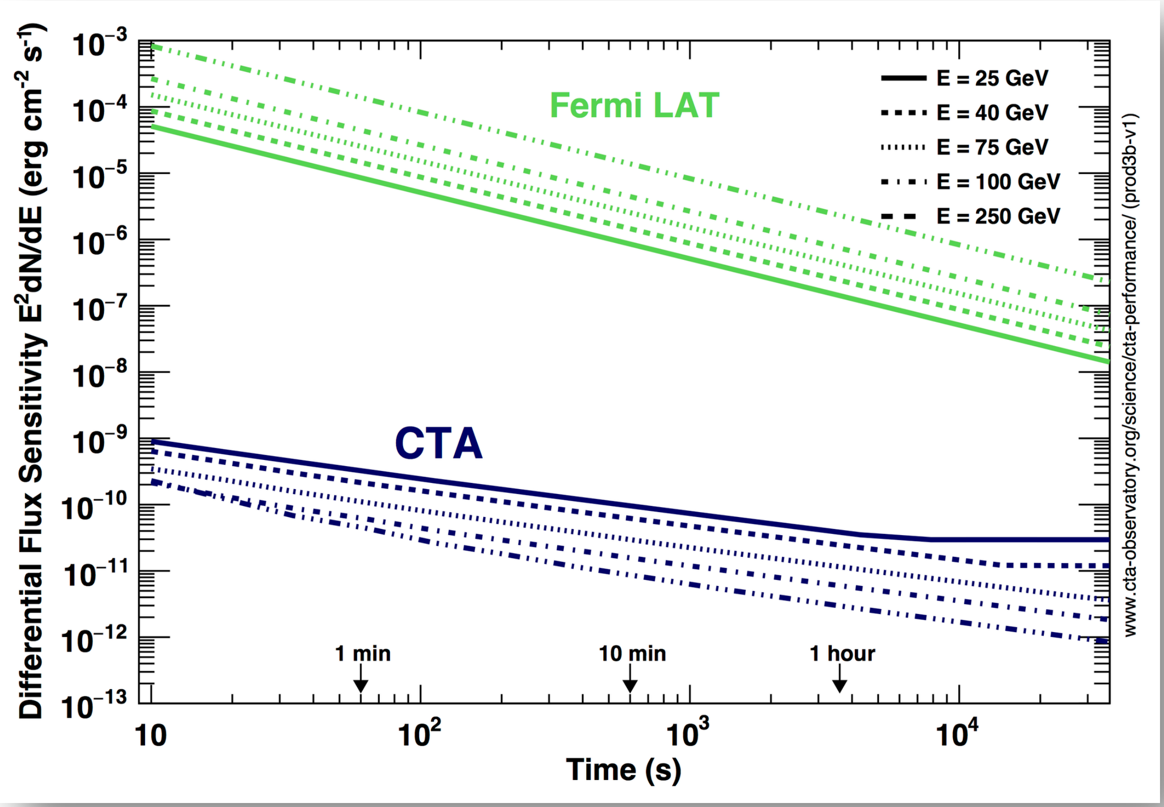
CTA as a *transient factory*

Huge advantage over Fermi in energy range of overlap for ~minute to ~day timescale phenomena

- Explosive transients
- AGN flares
- γ-ray binaries
- ***Real-time analysis SW is crucial***

Disadvantage over Fermi

- Limited FoV (compared to Fermi)
- Prompt reaction to external triggers is critical



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Science Themes

Theme 1: Cosmic Particle Acceleration

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

Theme 2: Probing Extreme Environments

- Processes close to neutron stars and black holes?
- Processes in relativistic jets, winds and explosions?
- Exploring cosmic voids

Theme 3: Physics Frontiers – beyond the SM

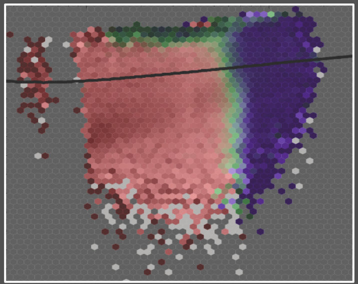
- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high energy photons?
- Do axion-like particles exist?

CTA Observing Programme

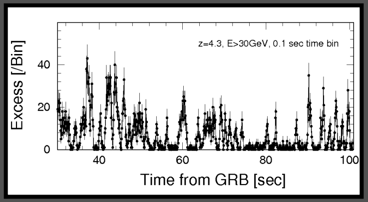
- **9 Key Science Projects** (KSPs) and **1 DM Programme**
  - **KSPs are a sets of observations addressing multiple science questions within CTA themes**

- Focused on **major legacy projects**:
  - surveys & population studies (providing legacy data-sets)
  - large classes of sources
  - a few iconic objects

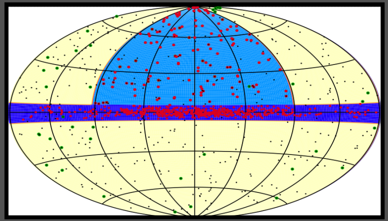
- Large potential for **guest observer proposals**
  - building on results from the KSP surveys



Dark Matter Programme



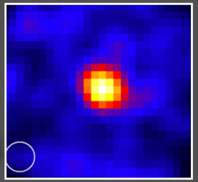
Transients



ExGal Survey

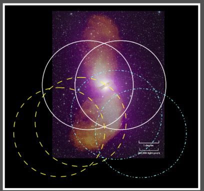
Extragalactic

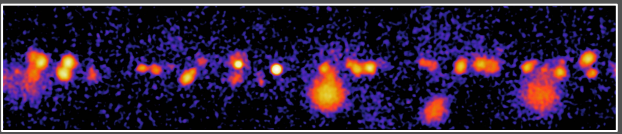
Galaxy Clusters



Star Forming Systems

AGN

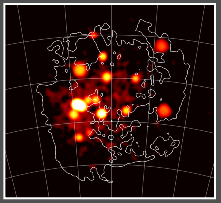




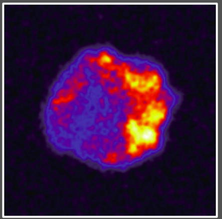
Galactic Plane Survey

Galactic

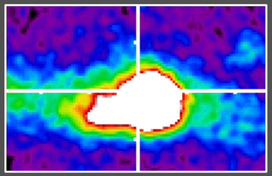
LMC Survey



PeVatrons



Galactic Centre Survey



cta
cherenkov telescope array

Science with CTA

200+ pages describing CTA science goals

arXiv:1709.07997

To be published as a book & open-access online version by World Scientific.

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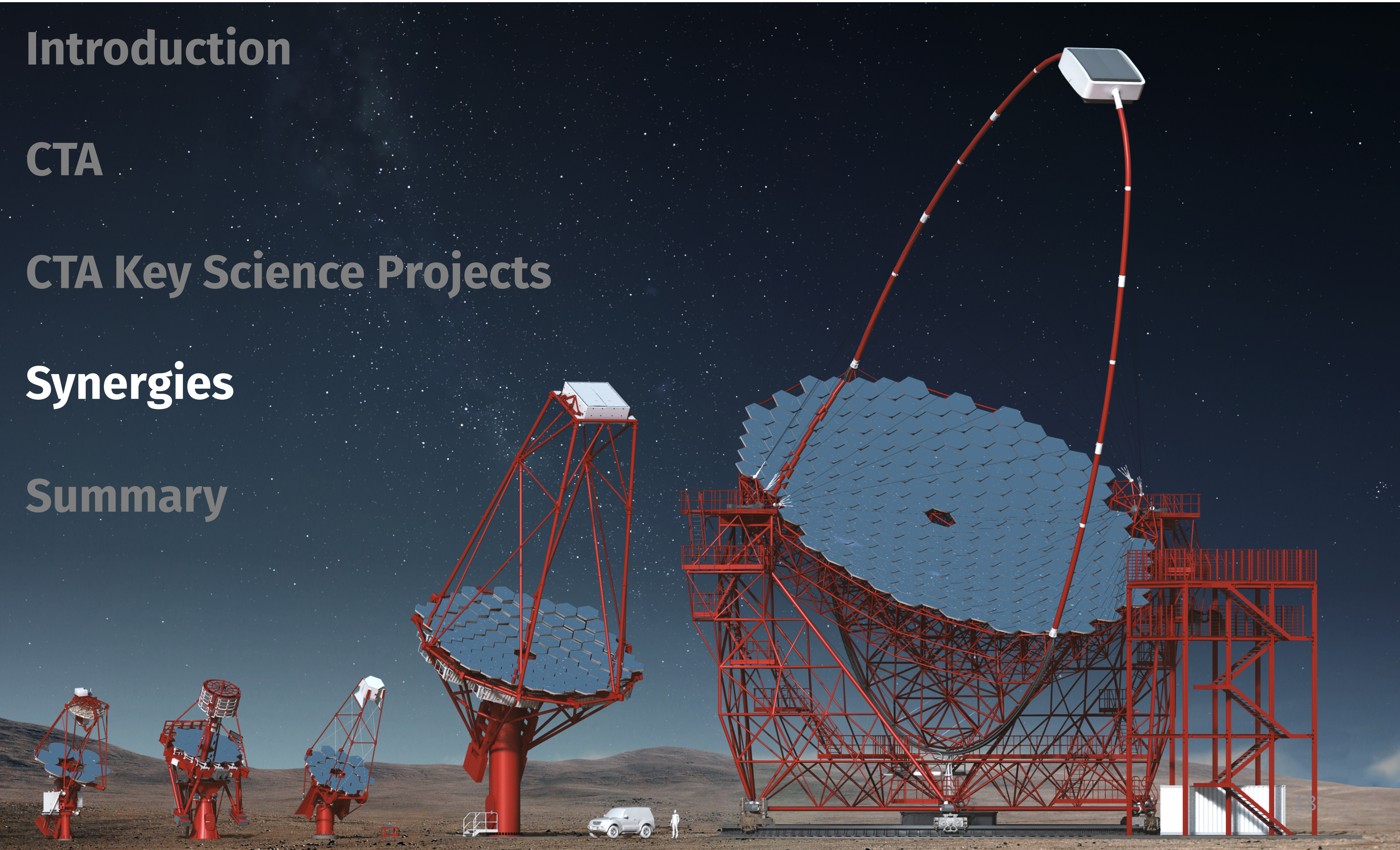


KSPs vs. proposal-driven programs

Key Science Projects

- Ensure that important science questions for CTA are addressed in a coherent fashion and with a well-defined strategy,
- Conceived to provide legacy data sets for the entire community

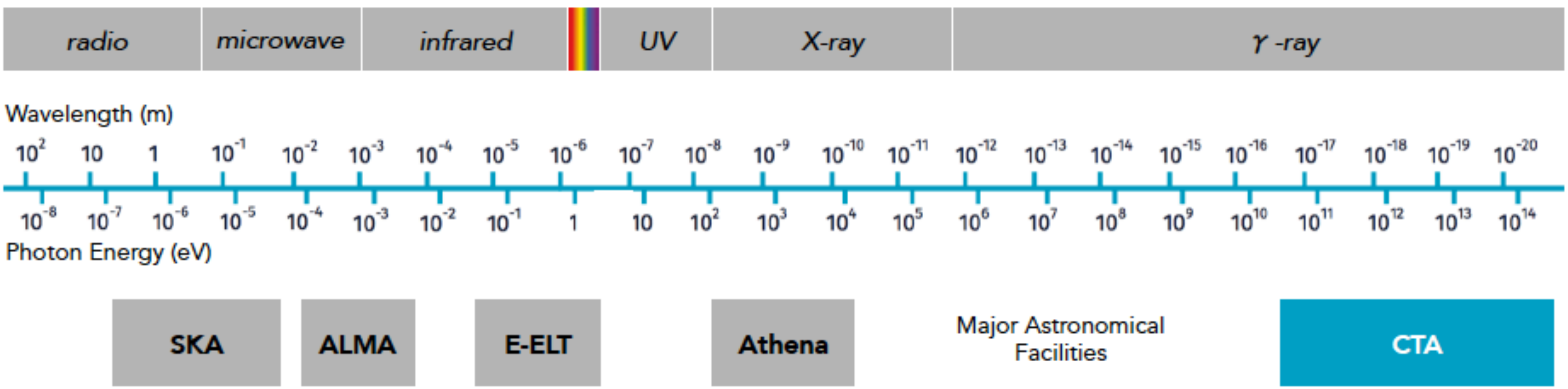
Example: galactic and extragalactic surveys

- Deep investigation of known sources
- Follow-up of KSP discovered sources
- Multiwavelength campaigns
- Follow-up of ToOs from other wavebands / messengers
- Search for new sources
- …

Proposal-Driven User Programme

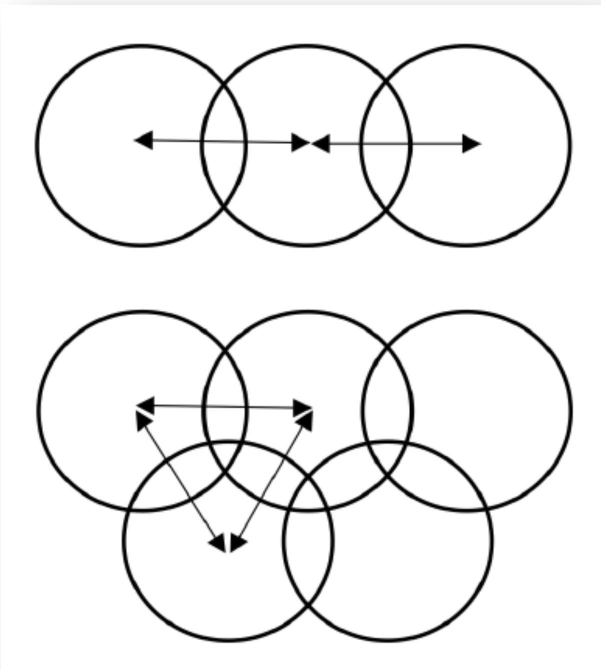
Credits: Hofmann, Gamma 2016

Synergies during CTA operation



These are just a few of the future major multi-wavelength facilities available during the CTA era at lower energies.

Galactic Plane Survey



Single-row scheme uses a uniformly-spaced single row of pointings that lie along the Galactic plane ($b = 0^o$)

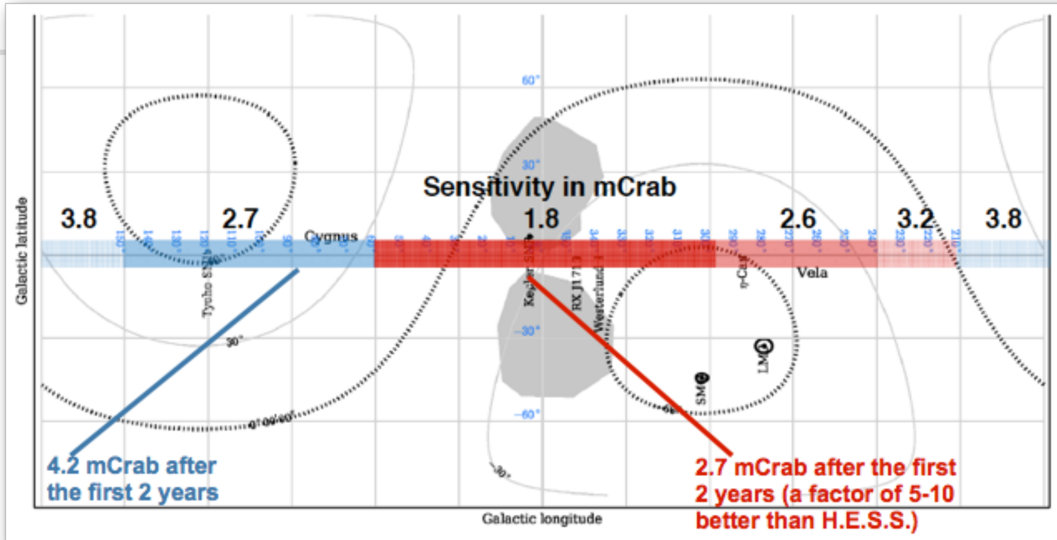
The **double-row** scheme uses pointings that lie above and below the $b = 0^o$ line and that have a uniform spacing between adjacent points in the same row and between nearest points in different rows.

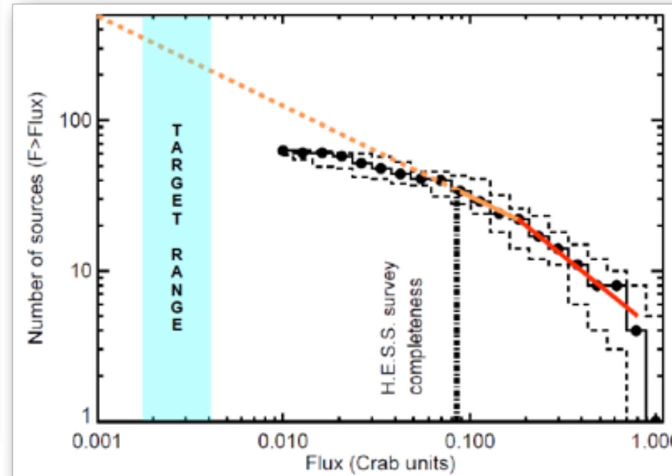
Both pointing strategies will be satisfactory to achieve the desired sensitivities.

Double-row scheme is preferred because it offers better performance at larger Galactic latitudes ($|b| > 2^o$) and more uniform sensitivity along the plane, and it may be more robust during background subtraction.

Optimal separation distance among pointings is 3^o

Galactic Plane Survey





- **Discovery of PeVatron candidates ➡** origin of cosmic rays
- Detection of many **new VHE** sources **O(300 – 500)**, particularly **PWNe and SNRs**
- Discovery of **new VHE gamma-ray binaries**
- Production of a multi-purpose **legacy data set**
- **Radio/mm and X-ray facilities** →PSR ephemerides, **PWNe/SNRs morphology**/SEDs, MWL **phase-resolved studies in binaries**, **cross-correlation of catalogs** and identification of new VHE sources, …
- **Non-thermal X-ray emission** → a natural **tracer of locations of extreme particle acceleration.**

Galactic Plane Survey

Telescope	Hemisphere	Galactic Plane Coverage	Energy (GeV)	Sensitivity (mCrab)
Fermi-LAT 2FHL	(space)	full plane	> 50	~30 – 40
H.E.S.S.-I	S	$-95° < l < 60°$, $\lvert b\rvert \lesssim 2°$	$\gtrsim 300$	4 – 20
VERITAS	N	$67° < l < 83°$, $-1° < b < 4°$	$\gtrsim 300$	20 – 30
ARGO-YBJ	N	northern sky	> 300	240 – 1000
HEGRA	N	$-2° < l < 85°$, $\lvert b\rvert < 1°$	> 600	150 – 250
Milagro	N	northern sky	$> 10,000$	300 – 500

Current GPS surveys

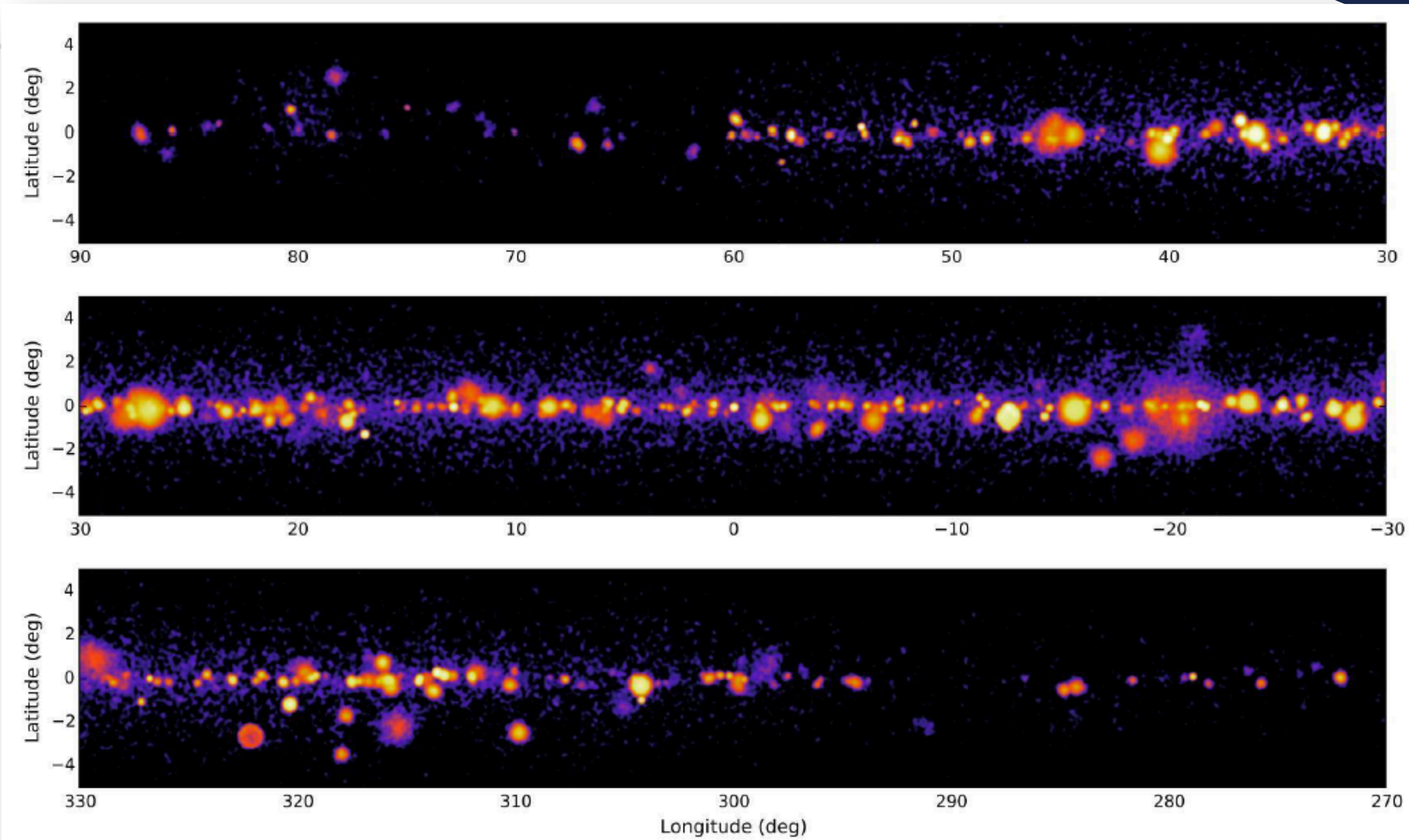
CTA GPS survey

	STP (Years 1 – 2)		LTP (Years 3 – 10)	Total (Years 1 – 10)	
Galactic Longitude	**Hours**	**Sensitivity**	**Hours**	**Hours**	**Sensitivity**
SOUTH					
300° – 60° , Inner region	300	**2.7 mCrab**	480	780	**1.8 mCrab**
240° – 300° , Vela, Carina			180	180	**2.6 mCrab**
210° – 240°			60	60	**3.1 mCrab**
				1020	
NORTH					
60° – 150° , Cygnus, Perseus	180	**4.2 mCrab**	270	450	**2.7 mCrab**
150° – 210° , anti-Centre, etc.			150	150	**3.8 mCrab**
				600	

Observatory	Hemisphere	Energy Thresh.	Ang. Resolution	Pt. Source Sensitivity
CTA	N, S	125 GeV	$\sim 0.07°$ at 1 TeV	2 – 4 mCrab
HAWC	N	2 TeV	$0.30°$	20 mCrab

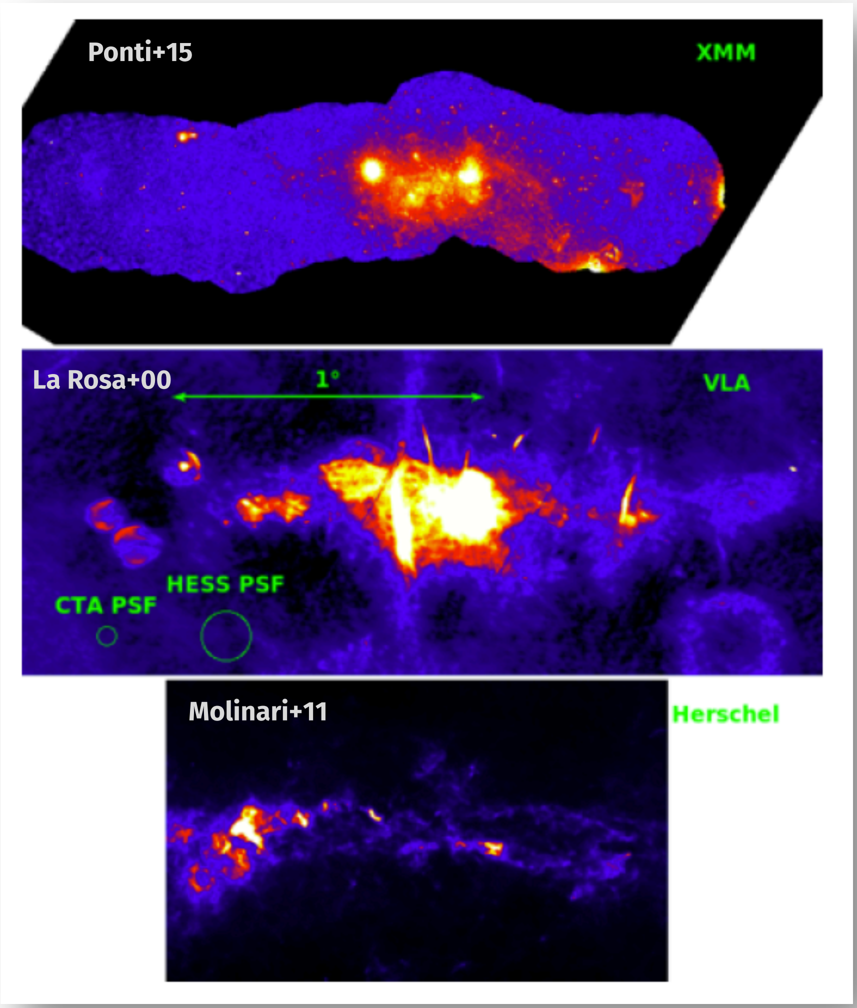
CTA/HAWC survey performance

Galactic Plane Survey



Simulated CTA image of the Galactic plane for the inner region 90º < l < 90º, adopting the actual proposed GPS observation strategy, a source model incorporating both **supernova remnant and pulsar wind nebula populations and diffuse emission**

Galactic Centre Survey



Multi-wavelength view of the **inner Galactic Centre region**, showing the **wide variety of diffuse emission.**

The CTA point spread function is shown in comparison with that of the presently operating H.E.S.S. telescope to illustrate the **possibility of resolving structures with CTA that are point-like with existing instruments**.

Galactic Centre Survey

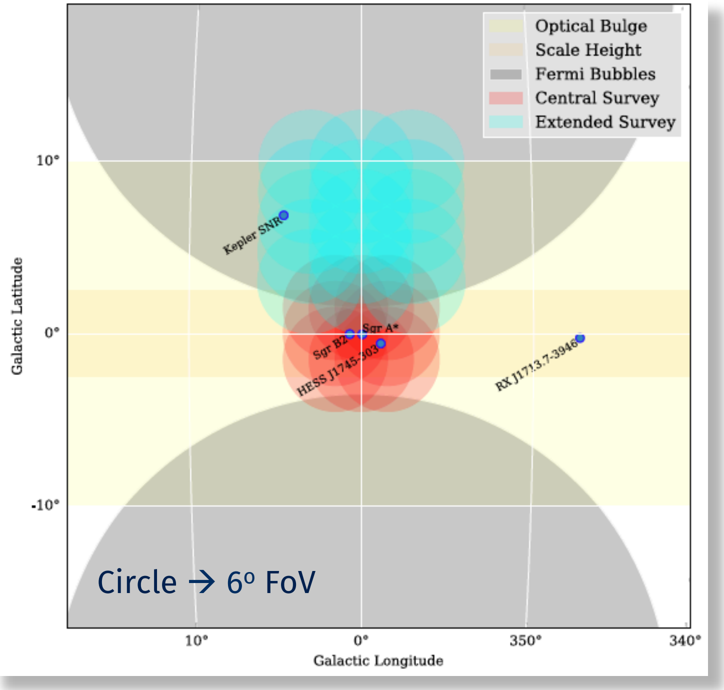
	Deep Exposure	Extended Survey
Time requested	525 h	300 h
Priority	1	3
Strategy	survey	survey
Site	S	S
Sub-array	Full	Full
Zenith Range	$< 40^\circ$	$< 50^\circ$
Atmosphere Quality	high	high
Targets Covered	multiple	multiple

Central survey region: a deep exposure of 525 h, centered on Sgr A*(l = ±1.0^o, 0^o and b = ±1.0^o, 0^o).

- **1st year** → updated analysis of the central source.
- **3rd year** → detailed study of the extended/diffuse emission will be possible + data for DM search.

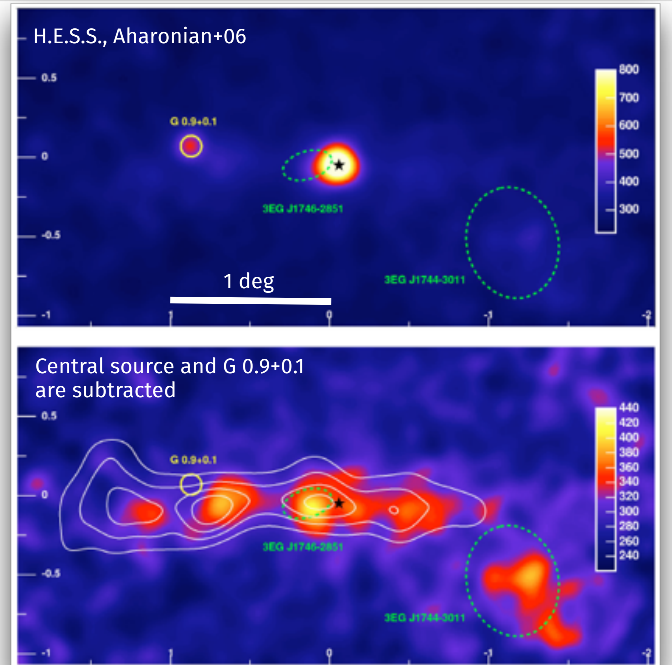
Extended survey region: 300 h of exposure covering a large region to the south or north of the GPS region out to 10^o in latitude.

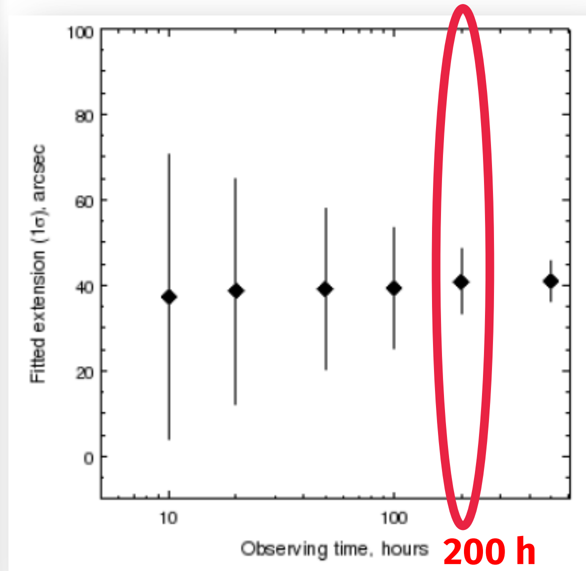
These observations can be taken after the deep exposure, i.e. after the third year of operation.



The CTA Consortium

Galactic Centre Survey





Expectation for the **fitted size of the central source** (assuming a Gaussian shape) made by CTA as a function of observing time.

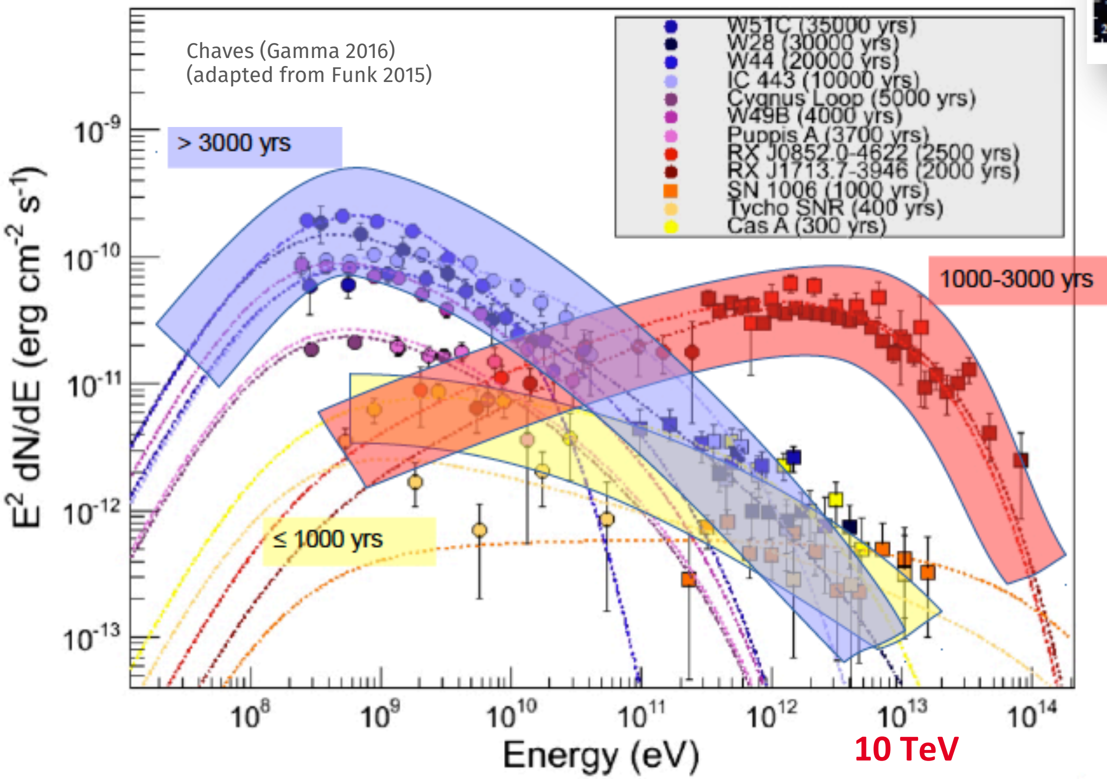
With 200 h, CTA should reach a detection of the source extent with a statistical significance of approximately four standard deviations

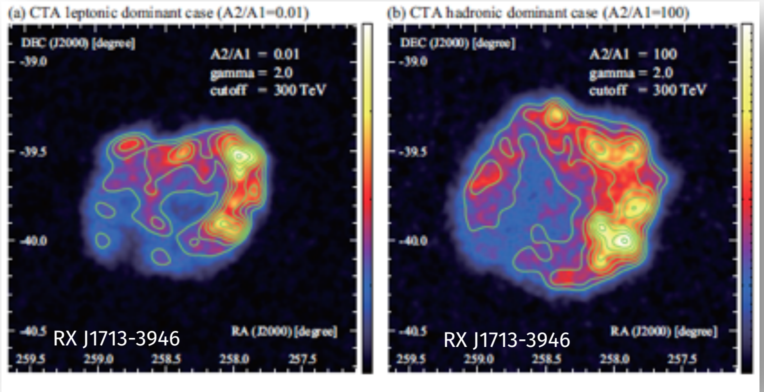
- Determination of the **nature of the central source**
- A detailed view of the **VHE diffuse emission**
- Search for **variability** in the VHE source near **Sgr A***
- Studying the **interaction of the central source with neighboring clouds**
- Global **VLBI array at mm/sub-mm frequencies**, → direct **imaging of the jet-launching regions** of key sources such as Sgr A*
- AGNs **optical polarisation** studies of jets → derivation of **magnetic field parameters** that can be used to improve SED modeling and emission-region localisation

Cosmic-ray PeVatrons

What sources may accelerate hadrons to the knee?

SNRs are standard paradigm, but only a handful provide strong evidence for hadron acceleration so far, and only up to ~ 10 TeV



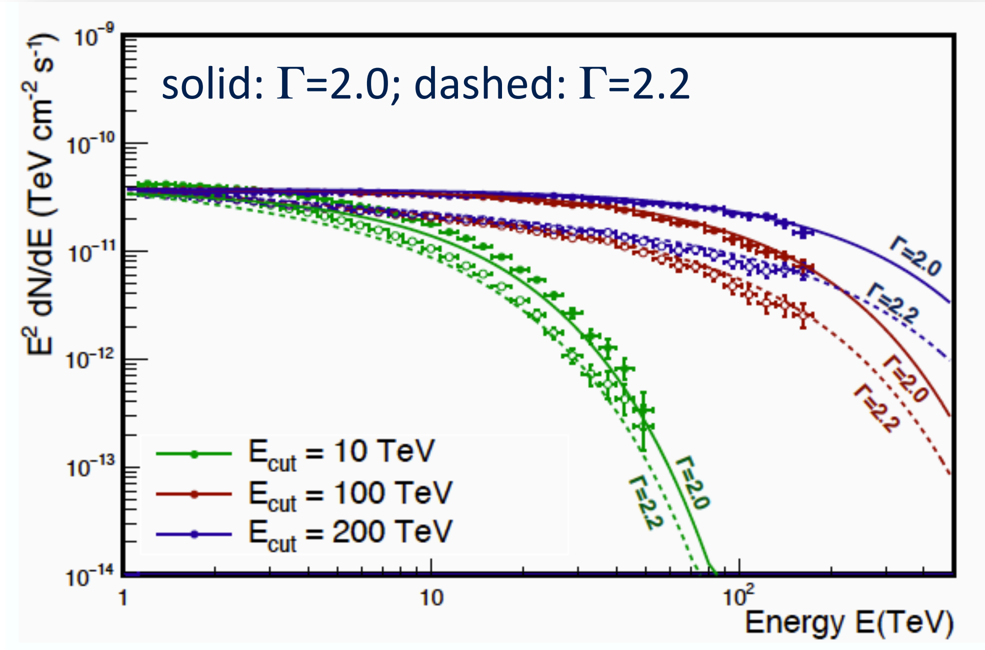


Nakamori et al., 2015 50 hr CTA simulation

The detection up to E ~100 TeV would imply:

- **the emission is hadronic**, because the leptonic emission is strongly suppressed at such high energies due to the Klein-Nishina effect;
- **the SNR is a PeVatron**, because ~100 TeV photons are produced by ~PeV protons.

Cosmic-ray PeVatrons



Simulated **reconstructed spectra for CTA for a PeVatron-like source** with a flux equal to the Crab nebula, using two photon indices.

Three different exponential energy cutoff values are used, as indicated by the colors.

Target	Type	Exposure (h)	Array	Year	Configuration
RX J1713.7–3946	SNR	50	S	$1-3$	Full array
PeVatrons	Unknown	5×50	S	>3	MSTs + SSTs

Use **GPS as finder** and **follow-up 5 brightest sources with no cut-off.**
MWL information critical for identification.

Multi-messenger Astrophysics window is open !

Detection of a gravitational wave event following a GRB onset and its MWL follow-up

```
TITLE:    GCN CIRCULAR
NUMBER:   21916
SUBJECT:  IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE:     17/09/23 01:09:26 GMT
FROM:     Erik Blaufuss at U. Maryland/IceCube  <blaufuss@icecube.umd.edu>
```

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel

Credential

Subjects: Optical, Gam

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

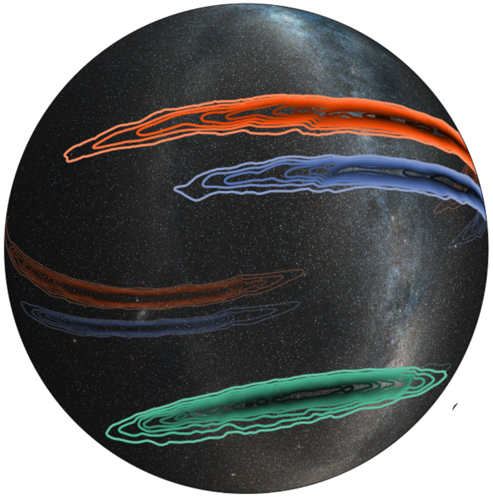
ATel #10791; ***Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration***
on ***28 Sep 2017; 10:10 UT***
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Possible association of an extra-galactic source with an IceCube neutrino event.

Transients

Credits: The LIGO Scientific Collaboration



Transients are a diverse population of astrophysical objects. Some are known to be prominent **emitters of high-energy gamma-rays,** while others are sources of non-photonic, multi-messenger signals such as cosmic rays, **neutrinos and/or gravitational waves.**

Transient Factories & SKA will generate an **overwhelming number of triggers.**

The **definition of appropriate response criteria** is the key to understand the potential for VHE follow-up

		Observation times (h yr^{-1} $site^{-1}$)			
Priority	Target class	Early phase	Years 1–2	Years 3–10	Years 1–10
1	GW transients	20	5	5	
2	HE neutrino transients	20	5	5	
3	Serendipitous VHE transients	100	25	25	
4	GRBs	50	50	50	
5	X-ray/optical/radio transients	50	10	10	
6	Galactic transients	150	30	0(?)	

Follow-up priority	Target class	Detected @ HE	Trigger	Rate (yr^{-1})	Urgency	Activity duration	Obs. time (h) /night	Total time (h)	Site
1	Magnetar giant flares	–	MeV	0.1	1 min	1–2 d	Max. 1	10	A/B
2	PWN flares: Crab nebula	Y	HE	1	1 d	5–20 d (HE)	4	50	S&N
3	HMXB microquasars: Cyg X-3	Y	HE/X-ray	0.5	1 d	50–70 d (HE)	Max. 1	50	N
	Cyg X-1	Y	HE/X-ray	0.2	1 d	1–10 d ?	Max. 1	30	N
4	Unidentified HE transients	Y	HE	1	1 d	?	2	20	A/B
5	LMXB microquasars	?	X-ray/radio	1	1 d	Weeks	2	20	A/B
6	Novae	Y	HE/opt.	2	1 d	Weeks	2	20	A/B
7	Transitional pulsars	Y	Radio/opt.	0.5	1 d	Weeks	2	20	A/B
8	Be/X-ray binary pulsars	N	X-ray	1	1 d	Weeks	2	20	A/B

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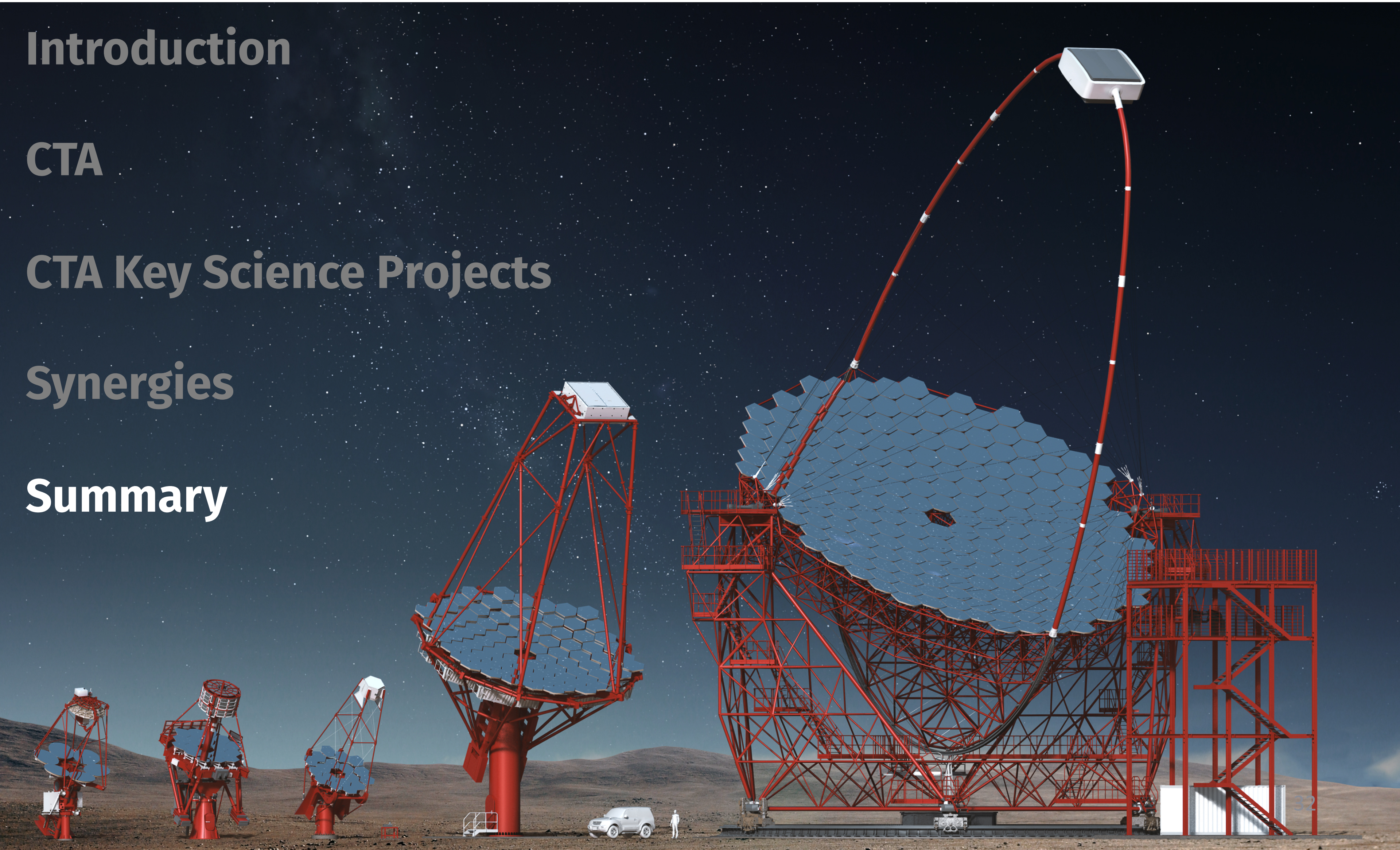

CTA will be an **Observatory** open to the scientific community.

Science will focus on cosmic particle acceleration, extreme environments, and physics beyond the standard model.

Proprietary time (significant fraction in the first years) will be articulated in **Key Science Projects.**

Large potential for **Guest Observer proposals** – e.g., building on results from the KSP surveys.

CTA will have important **synergies** with many astronomical and astro-particle facilities.